RESEARCH

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DISCOVERY

Modeling the diameter at breast height (DBH) with height and volume of *Shorea robusta* using destructive method: A study from Banke District, Nepal

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ABSTRACT

There is very good correlation between tree diameter, height and volume which is useful to evaluate and calculate the volume of standing trees but study regarding this is very limited in Nepal. Therefore, this research was objectively conducted to correlate diameter with height and volume and determine form factor of *Shorea robusta*. Banke district, Nepal was selected as study site. Altogether 70 healthy plants were selected and felled applying destructive method. The Shapiro–Wilk test and Kolmogorov-Smirnov test were done and box plot was prepared to check the normality so only 61 data were used for the research work. Out of this data of 47 trees were used for model equation development and remaining was used for validation purpose. The natural log regression was applied to develop the model between diameter at breast height (DBH) and height of the plants. The polynominal order 2 model was used to show the relation between volume and DBH and these models were validated. The results showed that r^2 value was 0.892and equation showing correlation between height and DBH was, height= 9.9414* ln (Diameter) - 11.666. The overall estimated tree from factor was 0. 0.493 and 0.462 of diameter over and under bark respectively. The equations of over bark volume equation for top diameter upto 20 and 10 cm as well as under bark volume for top diameter 20 and 10 cm were $y=0.0009x^2 + 0.0097x - 0.2113$; $y=0.0013x^2 + 0.0145x - 0.317$; $y=0.0008x^2 + 0.0104x - 0.2137$ and $y=0.0013x^2 + 0.0155x - 0.3206$ respectively whereas y stands for volume and x equals to DBH. The r^2 values were over 0.9 and ANOVA and t-test showed that there was significant relation between these variables at 95% confidence level. Moreover residual plots showed close to zero and the values of Root Mean Square Error (RMSE), ratio of RMSE to standard deviation (RSR), percent bias (PBIAS), Mean Deviation (MD) and Mean Absolute Deviation (MAD) were very less. The volume equation will be useful for forest science to calculate and evaluate the volume of standing plants.

Key words: local volume table, *Shorea robusta*, form factor, relationship

1. INTRODUCTION

The modeling the diameter at breast height (DBH) with height and volume is technical requirement to calculate the volume of any tree species (Burkhart and Tome, 2012, Charles et al., 2018). This provides the estimated height and volume without felling the trees (Chaudhuri and Pandey, 2016). The volume depends up on the local site quality and climate and non-climatic factors. World wise, this practice is famous to estimate the volume of standing trees (Hyytiäinen et al., 2004). India, Bhutan, Pakistan, China have also been developed the volume equation to estimate the volume of standing trees (Demeritt and McIntyre, 1932, Chiung et el., 2019, Mahmut, 2004). This practice has also initiated in some of parts of Nepal. However, there is still gap to prepare specific volume equation.

Estimation of stem volume through direct measurement is tedious, laborious, and costly task (Sharma and Parton, 2007). There are very limited models regarding the DBH, height and volume of tree species in Nepal. Volume equations developed by Sharma and Pukkala (1990) and compiled by Tamrakar (2000) are used to calculate the volume of trees in Nepal in general (DFRS, 2017).

Any model needs the independent variables and dependent variable (DoF, 2004). The model like correlation between DBH and height as well as DBH and volume also require at least two variables (Fulton, 1999). Generally, biophysical variables like diameter at breast height, height, form factor, volume are modelled for several purposes in forest environment science. The volume equations models are applied for specific areas because, if it is prepared based on the small geographical data set. In fact, there are several factors that affect precision of the volume table (Avery and Burkhart, 2015). The volume equation of one tree species is not used for another tree species (Khanna and Chaturvedi, 1982). There are huge gaps in modelling of DBH with the height, form factor and volume of important tree species like *Shorea robusta*. Therefore, the essence of this study was to develop the model showing the correlation of tree height, volume with the diameter at breast height also assess the form factor for this species.

2. METHODOLOGY

Method of Model Development

Site selection and sampling

Banke district in province number 4 was selected as the study site. The samples were collected from the where the felling operation were carried out. Thus, block forests were selected for the study site (Figure 1). Generally, big trees (tree having DBH>30 cm) were felled in the felling coupe but the less than this diameter class was not felled. So, there was some problem to record data DBH<30 cm. Therefore, a request was made to harvest the trees of such diameter class.

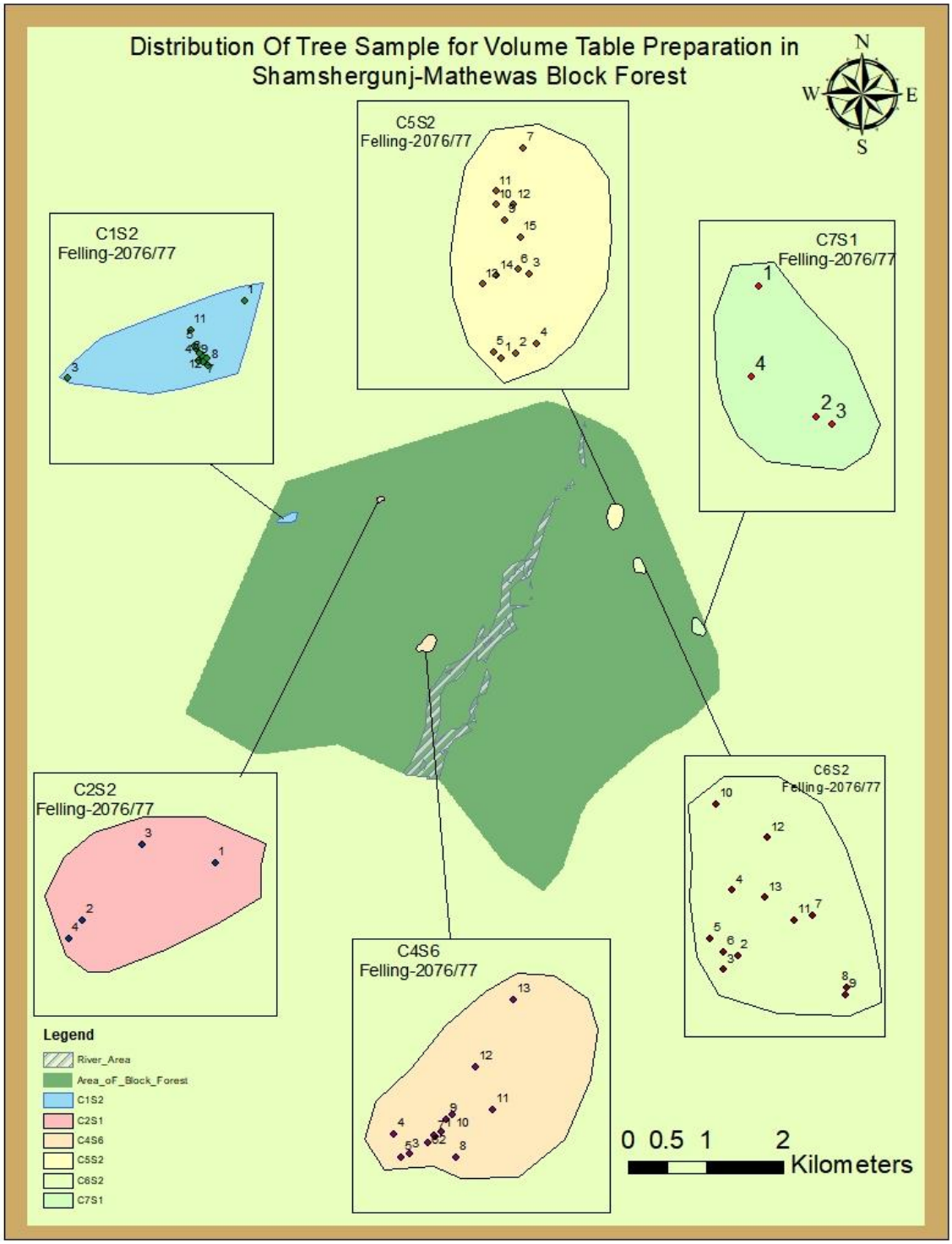

Figure 1: Study site showing in Banke district map

Banke district is situated between 28.3649° N latitude and 81.5596° E longitude in Terai region, a part of Province No. 5 in the mid-western part of our country Nepal. Most of the district is drained by Rapti, except district's western edge is drained by Babai River. Rapti and Babai Rivers cross into Uttar Pradesh, a state in India, Nepal's neighboring country and eventually join Karnali and it's name has changed there as Ghaghara. The elevation of study area ranges between 153 to 1,247 m above the mean sea level. Mean maximum temperature is around 40 °C in summer but drops to very low during winter. Seasons are of four types, monsoon (June–September; the wet season with abundant rainfall), autumn (October–November), dry winter (December–February) and spring (March–May) (DFO, 2019).

Forest in three climatic zones namely Lower Tropical with elevation range below 300m covering area of 79.1%, Upper Tropical climatic Zones with elevation range 300-1000m covering area of 20.6% and Sub-Tropical with elevation range 1000-2000m covering area of 0.3%. *Shorea robusta* is the dominat plant species in this district while the associated species are *Anogeissus latifolia, Bombax malabaricum, Lagerstroemia parviflora*, *Buchaniana latifolia, Dillenia pentagyna*, *Semecarpus anacardium*, *Phyllanthus nepalensis, Terminalia belarica, Bixa orellana, Acacia catechu, Lagestomia indica, Trewia nudiflora*.

Plant selection, measurement and felling

Healthy plants having straight and clear bole were selected randomly for the study (Ormerod, 1973, Van Laar, and Akça, 2007). Altogether 70 trees were selected and these were marked representing from different diameter class of *Shorear robusta* in Banke district. The diameter class was maintained 0-10, 10-20, 20-30, 30-40, 40-50, and DBH> 50 cm. The height and diameter at breast height were measured before felling the trees. Next, the trees were felled applying destructive method and section was made. Before this, the diameter above bark and under bark was measured. In the beginning, the measurement was recorded at 0.5 m section interval up to 1.5 m log length and then 1.5m section. Cross sections were cut maintaining the least taper. Thus, the data collection sheet was prepared before going to collect the data from field for local volume table preparation. This data collection sheet includes the measurement of Diameter, height, condition of the forest as well. The team was prepared to collect the filed data and prepare the report.

Analysis of field data

The analysis of data includes the formula for volume calculation, number of data set used for model development, data cleansing, model development and reliability check.

Formula used for volume calculation

Collected data were arranged in the sheet of Microsoft excel. These data were analyzed using different software like Microsoft excel and Statistical Package for the Social Sciences (SPSS).

Actual volume of each section was calculated applying following formulae

i. Volume and fuel wood calculation

a) Total volume (V)= $V_1+V_2+V_3+V_{n-1}+V_n$

Whereas the total volume is the sum of the volume of all section and the section volume will be calculated using the Smalian's formula

b) Volume of each section of log will be calculated maintaining the less taper using Smalian's formula

$V= \frac{S_1+S_2}{2} \times L$

Model development (Equation development)

Total 61 trees were measured representing from different diameter class. Out of this 47 trees from different class were used for development of model equation and remaining data set was used for validation purpose (Table 1).

Table 1: Number records used for model development and validation

Diameter class (cm)	No of tree measured	No of tree used for relation	No of tree used for validation	Remarks
1 - 9	5	3	2	
10 - 19	9	7	2	
20 - 29	6	6	0	
30 - 39	11	9	2	
40 - 49	8	6	2	
50 - 59	8	6	2	
> 60	14	10	4	
Total	61	47	14	

The data were prepared to develop the model equation. Thus, the normality test was applied to check the data set. The normality test was done using Shapiro–Wilk test and Kolmogorov-Smirnov normality test, box plot was prepared to check whether all the data set falls under the first and third quartile or there is any outlier as well. The out liars were removed and models were developed with remaining data set. This process was applied to checking the data set of diameter and height distribution as well as the volume. Out of 70 trees only 61 trees were showed the normality so remaining 9 trees were not used for model development. Out of this 47 trees from different class were used for development of model equation and remaining data set was used for validation task.

The natural log regression was established between diameter at breast height and height of the plants. Next, the smooth curve was drawn to determine the height of the plant.

$\ln h = a + b \times DBH$

Whereas, Lnh is natural log height and DBH is the diameter at breast height,

The volume was estimated based on the height and DBH applying above formulae and section wise form factors. The assumption of local equation is same diameter has same height and same volume of a specific species. So, the polynominal order 2 was used to show the relation between volume and diameter at breast height.

$y = ax^2 + bx + c$ whereas y is the volume of the tree and x is the diameter at breast height, a,b and c are the constants.

Model validation and precision evaluation

The model validation is one of the important components of any model (Inoue, 2006, Bokalo et al., 2013). The validation was done applying two different ways (Bokalo et al., 2007, Socha and Kulej, 2007). First of all, 14 data set representing each diameter classwere used to compare the difference (residual) between the actual volume and predicted volume.

Difference (residuals)= Predicted volume- Observed volume.

The graph was plotted using the residuals point. The residuals points falls near the zero shows the high precision of the model. In addition, the predicted values were compared with the other models which were developed by different authors.

Moreover, the significance of allometric equations was checked by applying the F-test and t-test. At the same time, the Root Mean Square Error (RMSE), RMSE to the standard deviation (RSR) and percent bias (PBIAS) were also applied to compare and evaluate the predicted values and observed values for accuracy assessment using the following formula

X_{obs} indicate the observed data and X_{pre} indicates the predicted values.

$$RMSE = \sqrt{\sum (X_{obs} - X_{Pre})^2}$$

$$RSR = \frac{RMSE}{Standard\ deviation\ of\ observed\ data}$$

$$Standard\ deviation = \sqrt{\sum \frac{(X - \overline{X})^2}{n}}$$

Whereas, X indicates the records of the observed data and $\bar{X}$ is the mean of the observed data set, n is the number of observation,

Percentage bias (PBIAS) $PBIAS = \frac{\sum (X_{obs} - X_{pre}) \times 100}{X_{obs}}$

(Demaerschalk, 1972, Kothari, 2004)

Mean absolute deviation (MAD) or Mean Bias (MB) $MAD = \frac{\sum |(X_{obs} - X_{pre})|}{n}$

Deviation of residuals (SDR) $SDR = \sqrt{\sum \frac{(X_{obs}-X_{pre})-\{(X_{obs}-X_{pre})/n\}^2}{n-1}}$

X_{obs} indicate the observed data and X_{pre} indicates the predicted values.

3. RESULTS

Correlation between height and diameter

The equation was developed between diameter at breast height and height of the tree. The R^2 value was 0.892, R value was 0.931, adjusted R^2 value was 0.865and standard error of the estimate was 2.78 (Table 2). The equation showing correlation between height (dependent variable) and diameter at breast height (DBH) was y= 9.9414*ln(x)- 11.666 (Figure 2), whereas the y stands for dependent variable height (m) and x denotes the independent variable diameter at breast height (cm). The ANOVA showed that, the regression showing the correlation between height and diameter at breast height was significant at 95% confidence level. The t-test showed that the equation showing the correlation between height (dependent) and diameter at breast height (independent) significant since the p- value was less than 0.05.

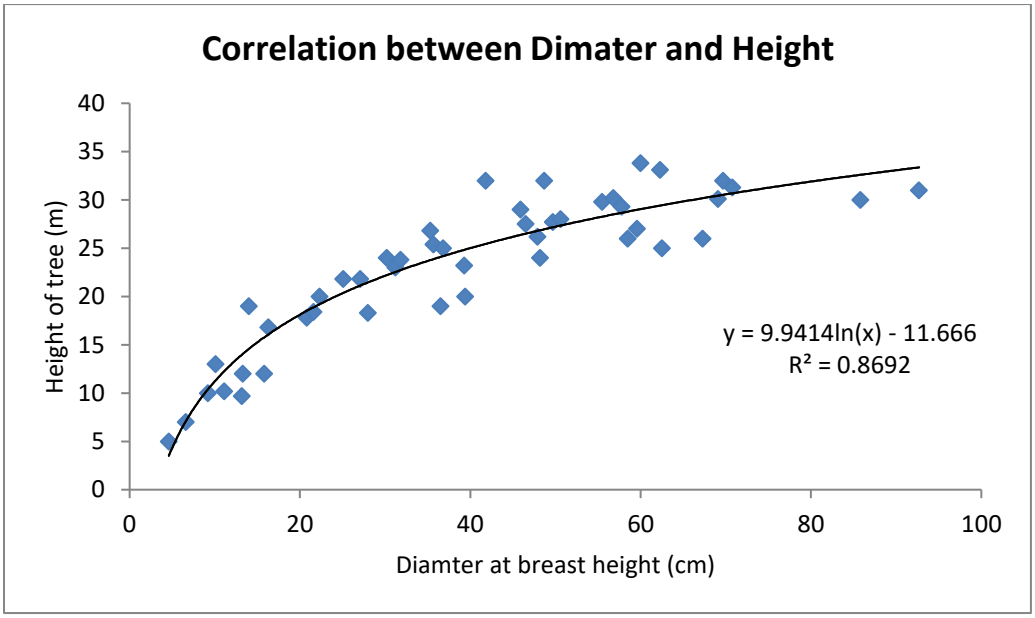

Figure 2: Correlation between DBH and height

Table 2 Model Summary of DBH and Height

Model Summary			
R	R Square	Adjusted R Square	Std. Error of the Estimate
0.931	.867	.865	2.768

The estimated value of RMSE, RSR, PBIAS, MAD and SDR showed less 5.48, 3.742, 0.292, 2.145 and 0.404 respectively so the equation is highly precise (Table 3).

Table 3 Errors in Predicted and observed values

SN	Details	Values	Remarks
1	RMSE of predicted and observed height (correlation)	5.48	
2	RMSE to the standard deviation (RSR)	3.742	
3	Percent bias (PBIAS)	0.292	
4	Mean Absolute deviation (MAD)	2.145	
5	SDR (Deviation of residuals)	0.404	

Residual plot of predicted height and observed height of the tree: The residuals plots of predicted and observed height of the trees showed that the most of the points falls close to zero (Figure 3). Thus, the equation showing the height and diameter at breast height of the trees is more precise.

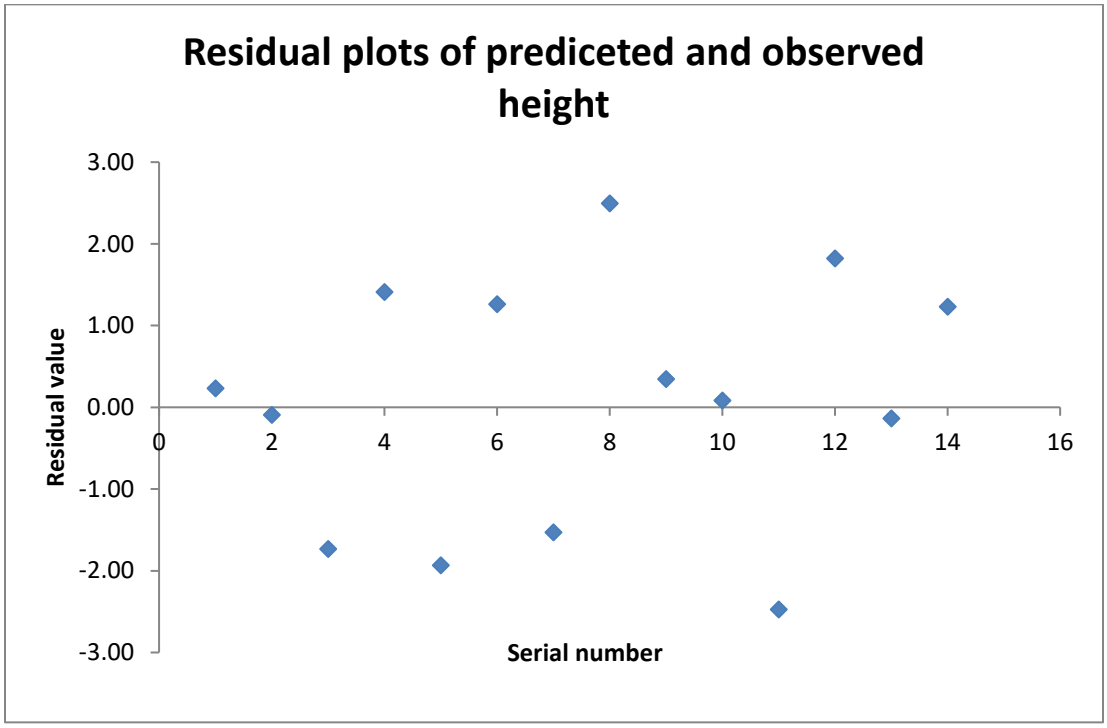

Figure 3: Residual plot of predicted and observed value from equation of DBH & tree height

Form factor of the tree at different diameter class

The form factor varies according to the diameter class under and over bark. Over all estimated from factor was 0. 0.493 and 0.462 of diameter over and diameter under bark respectively . The form factor was high at lower diameter class and it was the low at higher diameter class (Figure 4).

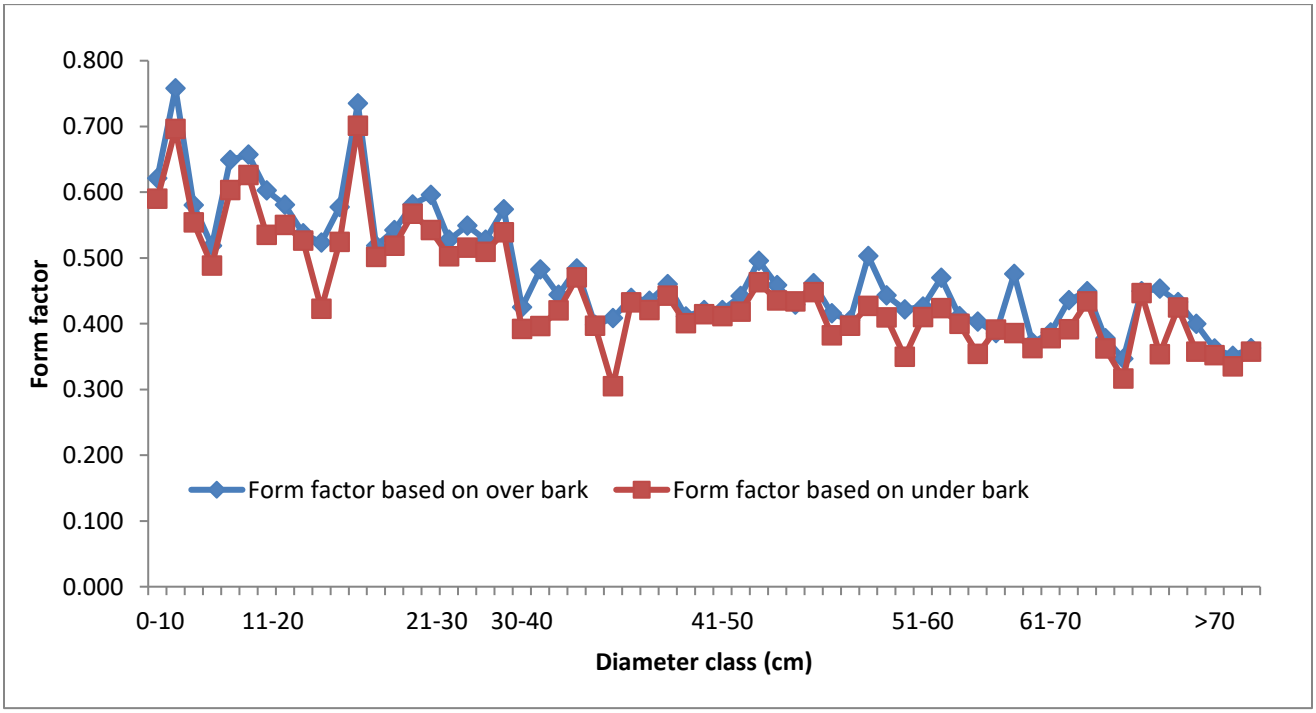

Figure 4: Plotting of form factor according to diameter class

Volume models of *shorea robusta*

The volume equation and table varied according to over bark and under bark of top diameter upto 20 and 10 cm.

VOLUME OVER BARK OF TOP DIAMETER UPTO 20 CM: The model summary showed that the values of r, r square, adjusted r square and standard error were 0.959, 0.920, 0.919 and 0.389respectively (Table 4).

Table 4: Model summary of equation of DBH and volume over bark of top diameter upto 20

Model Summary			
R	R Square	Adjusted R Square	Standard Error of the Estimate
0.959	0.920	0.919	0.389

There was very good relation between DBH and volume over bark of top diameter upto 20 cm with r^2 value 0.9724 and the equation was $y=0.0009x^2 + 0.0097x - 0.2113$, whereas the y equals to volume (m^3) and x is the diameter at breast height (DBH cm) (Figure 5).

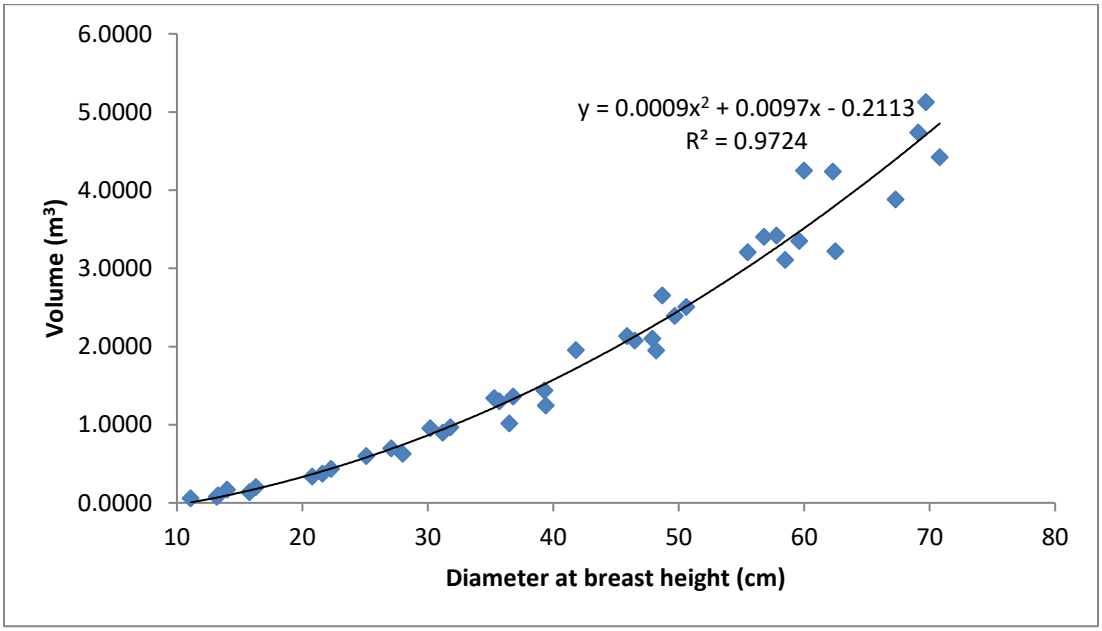

Figure 5: Relation between DBH vs Volume over bark upto 20 cm top diameter

ANOVA showed that there was significant correlation between them and t-test also showed that at 95% confidence level. The relation between DBH and volume over bark of top diameter upto 20 cm showed that the slope and constant both are significant at 95% level of confidence of the equation.

VOLUME OVER BARK OF TOP DIAMETER UPTO 10 CM: The model summary showed that the values of r, r square, adjusted r square and standard error were 0.986, 0.972, 0.972 and 0.212 respectively (Table 5).

Table 5: Model summary of equation DBH vs volume over bark of top diameter upto 10 cm

Model Summary			
R	R Square	Adjusted R Square	Std. Error of the Estimate
0.986	0.972	0.972	0.212

There was very good relation between DBH and volume over bark of top diameter upto10 cm with r^2 value 0.9724 and the equation was $y=0.0013x^2 + 0.0145x - 0.317$, whereas the y equals to volume (m^3) and x is the diameter at breast height (DBH cm) (Figure 6).

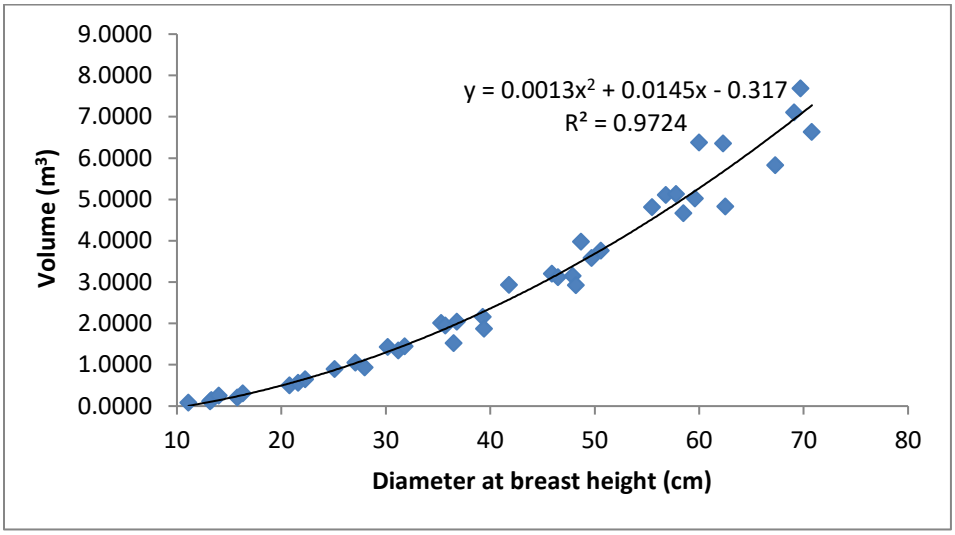

Figure 6: Model equation DBH vs volume over bark of top diameter upto 10 cm

The ANOVA showed that there was significant correlation between them and t-test also showed that at 95% confidence level. The relation between DBH and volume over bark of top diameter upto 10cm showed that the slope and constant both are significant at 95% level of confidence of the equation.

VOLUME UNDER BARK OF TOP DIAMETER UPTO 20 CM: The model summary showed that the values of r, r square, adjusted r square and standard error were 0.953, 0.908, 0.907 and 0.426 respectively (Table 6).

Table 6: Summary of DBH vs volume under bark of top diameter upto 20 cm

Model Summary			
R	R Square	Adjusted R Square	Standard. Error of the Estimate
0.953	0.908	0.907	0.426

There was very good relation between DBH and volume under bark of top diameter upto 20cm with r^2 value 0.9724 and the equation was $y=0.0008x^2 + 0.0104x - 0.2137$, whereas the y equals to volume (m^3) and x is the diameter at breast height (DBH cm) (Figure 7).

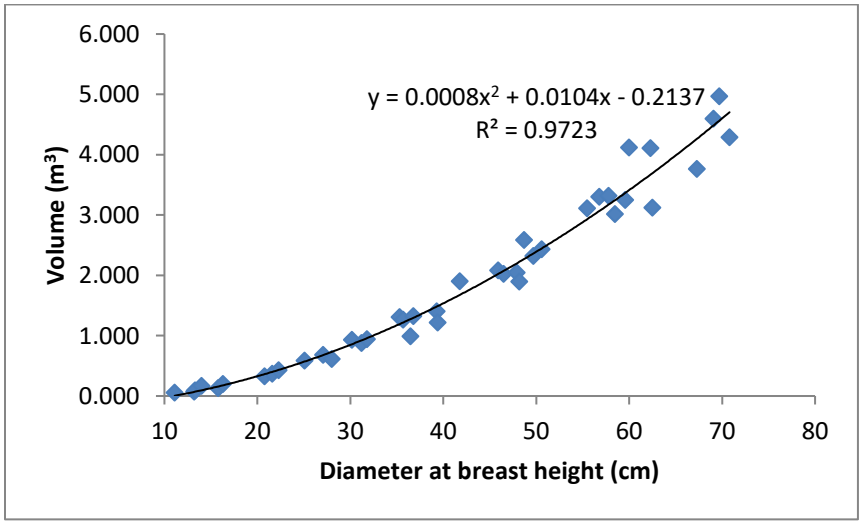

Figure 7: The graph showing DBH vs volume under bark of top diameter upto 20 cm

ANOVA showed that there was significant correlation between them and t-test also showed that at 95% confidence level. The relation between DBH and volume under bark of top diameter upto 20 cm showed that the slope and constant both are significant at 95% level of confidence.

VOLUME UNDER BARK OF TOP DIAMETER UPTO 10 CM: The model summary showed that the values of r, r square, adjusted r square and standard error were 0.961, 0.924, 0.922 and 0.376 respectively (Table 7).

Table 7: relation between DBH and volume under bark of top diameter upto 10 cm

Model Summary			
R	R Square	Adjusted R Square	Standard Error of the Estimate
0.961	0.924	0.922	0.376

There was very good relation between DBH and volume under bark of top diameter upto 10 cm with r^2 value 0.9723 and the equation was $y=0.0013x^2 + 0.0155x - 0.3206$, whereas the y equals to volume (m^3) and x is the diameter at breast height (DBH cm) (Figure 8).

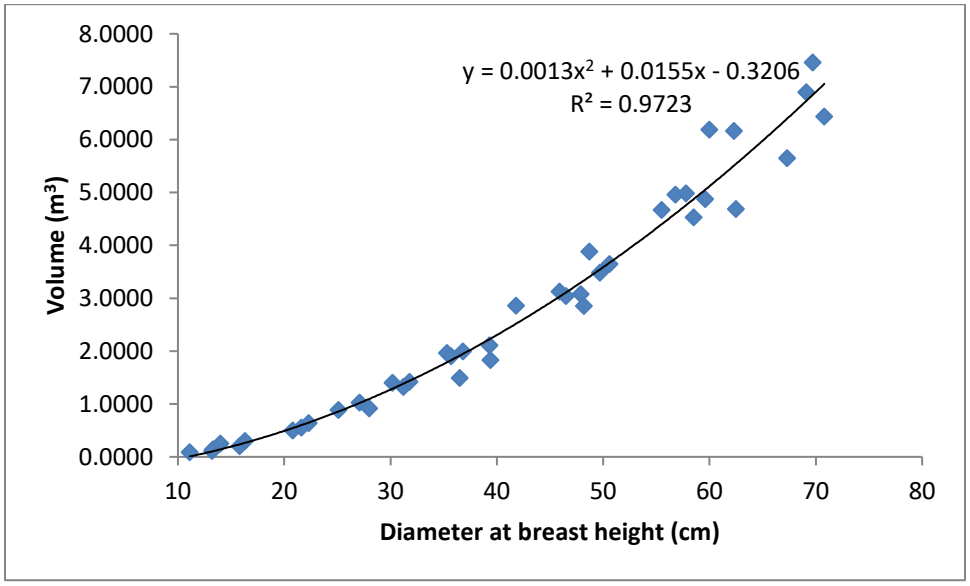

Figure 8: Graph showing DBH vs volume under bark of top diameter upto 10 cm

ANOVA showed that there was significant correlation between them and t-test also showed that at 95% confidence level. The relation between DBH and volume under bark of top diameter upto 10 cm showed that the slope and constant both are significant at 95% level of confidence of the equation.

Reliability and validation of local volume table and equation

It is essential to check the reliability of the model before employing it in the field. Thus, the descriptive analysis was done. In addition, the residuals were plotted and values of RMSE, RSR, PBIAS, MAD and SDR were calculated and presented.

DESCRIPTIVE STATISTICS OF THE PARAMETERS: The mean diameter including standard error was recorded about 40.829± 2.794cm while the minimum and maximum diameters were 11.1 and 70.8 cm respectively. Similar records were calculated to show the average height, volume over bark of top diameter upto 20 cm and vice versa (Table 8).

Table 8: Descriptive analysis of different parameters and predicted values

Statistical parameter	DBH (cm)	Ht (m)	Volume over bark		Volume under bark	
			top dia upto 20cm	top dia upto 10cm	top dia upto 20cm	top dia upto 10cm
Mean	40.829	23.822	1.913	2.869	1.861	2.792

Standard Error	2.794	1.003	0.232	0.348	0.225	0.337
Standard Deviation	17.891	6.730	1.487	2.230	1.441	2.161
Minimum	11.100	9.700	0.057	0.086	0.056	0.085
Maximum	70.800	33.800	5.125	7.688	4.972	7.458

RESIDUALS PLOT OF PREDICTED AND OBSERVED VOLUME OVER BARK OF TOP DIA UPTO 20 CM: The residuals of predicted and observed volume over bark of top diameter upto 20 cm was very close to zero line (Figure 9). Therefore, the model is reliable to use.

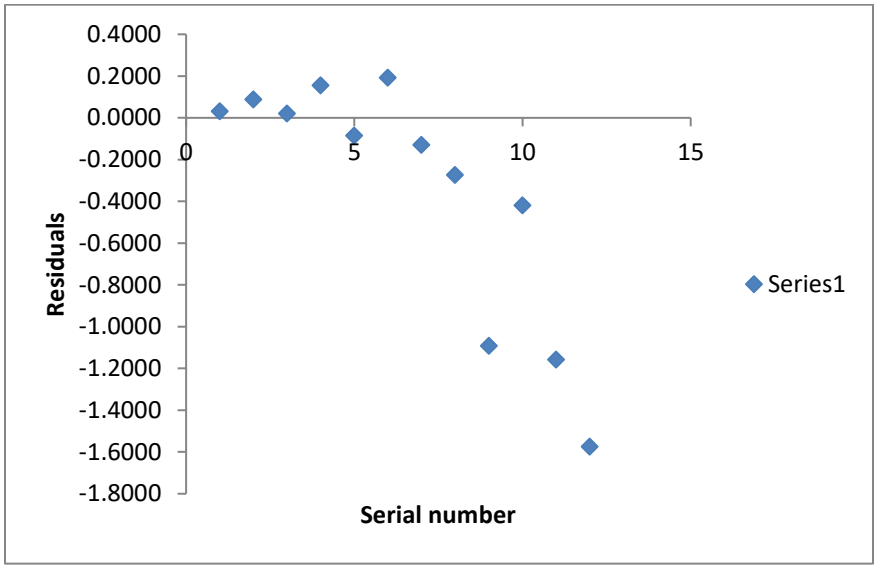

Figure 9: Residual plot of predicted and observed volume over bark of top dia upto 20 cm

RESIDUAL PLOT OF PREDICTED AND OBSERVED VOLUME OVER BARK OF TOP DIA UPTO 10 CM: The residuals of predicted and observed volume over bark of top dia upto 10 cm was very close to zero line. Therefore, the model is reliable to use (Figure 10).

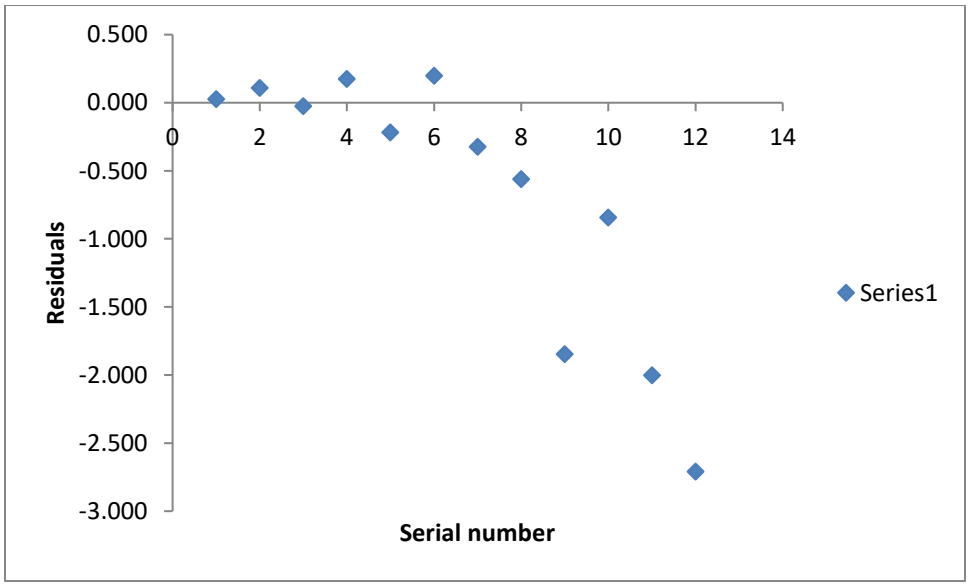

Figure 10: Residual plot of predicted and observed volume over bark of top dia upto 10 cm

*RESIDUAL PLOT OF PREDICTED AND OBSERVED VOLUME UNDER BARK OF TOP DIA UPTO 20 CM:*The residuals of predicted and observed volume under bark of top dia upto 20 cm was very close to zero line (Figure 11). Therefore, the model is reliable to use.

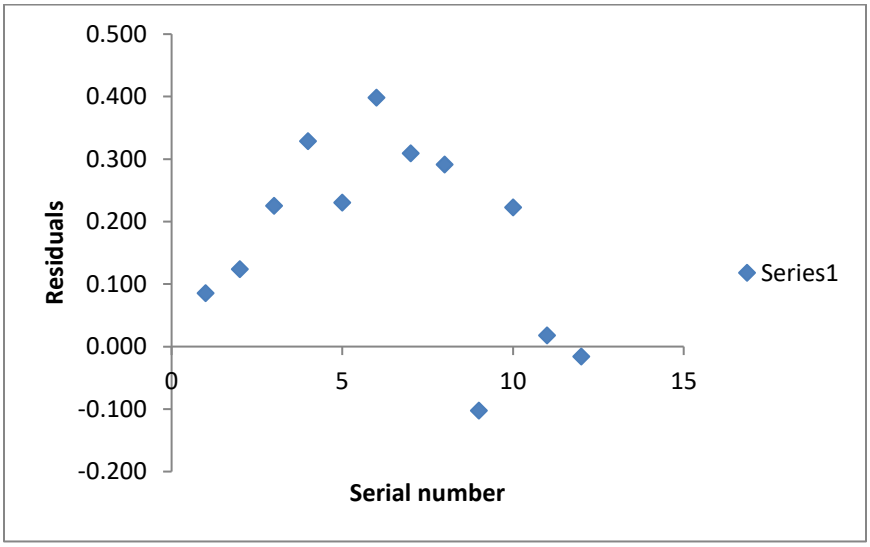

Figure 11: Residual plot of predicted and observed volume under bark of top dia upto 20 cm

RESIDUAL PLOT OF PREDICTED AND OBSERVED VOLUME UNDER BARK OF TOP DIAMETER UPTO 10 CM: The residuals of predicted and observed volume under bark of top dia upto 10 cm was very close to zero line (Figure 12). Therefore, the model is reliable to use.

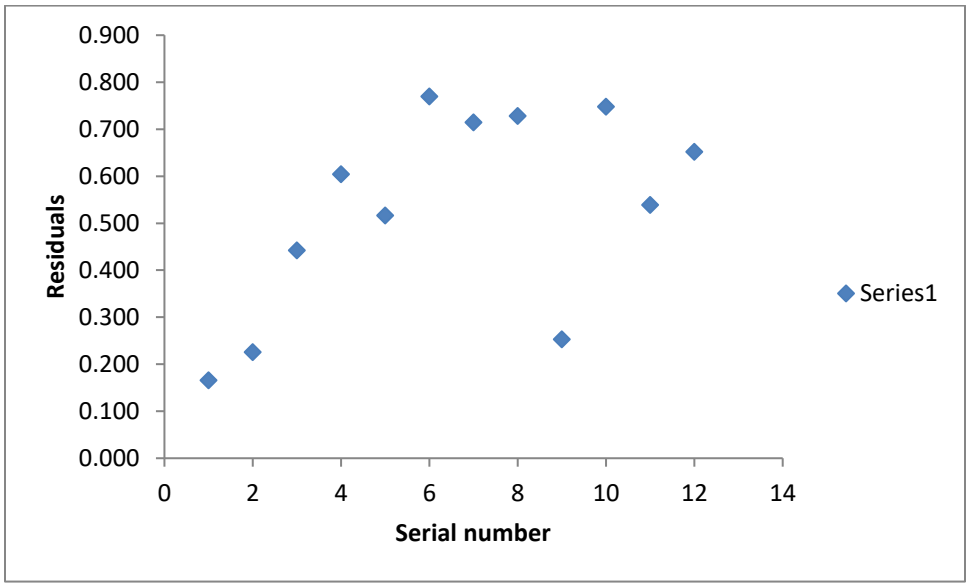

Figure 12: Residual plot of predicted and observed volume under bark of top dia upto 10 cm

LEVEL OF ERRORS IN VOLUME EQUATION: The root mean square error (RMSE), ratio of RMSE and standard deviation, percentage bias, mean absolute deviation (MAD) and deviation of residuals showed that the model is reliable and precise because these values were very less. Specifically, calculate RMSE was only 2.315 of volume over bark (top dia upto 20 cm) and vice versa (Table 9).

Table 9: Errors of the model

Description	Volume over bark		Volume under bark	
	top dia upto 20 cm	top dia upto 10 cm	top dia upto 20 cm	top dia upto 10 cm
RMSE	2.315	4.003	0.796	1.970
RSR	3.464	3.464	3.464	3.464
PBIAS	1.618	1.793	0.564	0.524
Mean absolute deviation	0.049	0.082	0.013	0.018

(MAD)				
Deviation of residuals (SDR)	0.232	0.298	0.118	0.140

4. DISCUSSION

There is an excellent relationship between the diameter at breast height and height of the tree. This research also showed an excellent relation. Several authors support this concept. Chaturvedi and Khan, (1982), Huang et al. (1992) and many authors showed this relation. Our finding showed that, as the diameter increases the height also increase but at a certain point height growth is constant. This concept is also supported by West and West (2009), West (2015).

The form factor is determined the tapering of the plant. Increasing diameter leads toward more taper shape of the plant ((Curtis, 1967). The higher the diameter the larger is taper and the lower value of form factor. This research showed that the form factor is more than 0.5 of DBH<40 cm while this was around 0.5 or less of DBH>40 cm. The concept of form factor based on the resisting capacity against the wind velocity is widely accepted in forest science. Most of the authors support this concept (Gray, 1956, Vallet et al., 2006). The theory developed by Metzger and Girder principle like the tree bole is working as cantilever beam against the wind pressure (Cailliez, (1980), Zhang et al., (1993), Muhairwe (1994). The tree form is affected by local edaphic, climatic and non-climatic factors (Tomlinson, 1983, Dodd et al., 1991, Grace& Norton, 1990), therefore, the different tree has different level of variation in tree form. The samples were collected from tropical forest of Banke district so the climatic and non-climatic factors of this area may affect on this. Another important factor is density, (Cregg, 1988) it was around 120 10 130 stems per ha.

Many variables determine the volume of the tree. The most common use variables are diameter at breast height, height, form factors and site quality (Muukkonen, 2007). Therefore, the volume models are based on multiple variables, two variables (diameter and height and single variable (diameter) (Demeritt and McIntyre, 1932, Abbot et al., 1997, Snorrason and Einarsson, 2006). This volume table was prepared based on diameter (Newnham, 1992, Zhou, 2008).

There are different techniques to validate the model of check the performance of the model (Meyer, 1940, Mugasha et al., 2016). Most common methods of checking the reliability of the model are plotting the residuals and are related to error estimation like root mean square error, ratio of root mean square error and standard deviation and so on (Cost 1979, Maltamo et al., 2004, Volkanovski et al., 2009). These all techniques were employed to check the model's performance in this research work.

5. CONCLUSION AND RECOMMENDATION

The relation between diameter and height was excellent and it was natural log relation. The values of form factor was decreasing according to increasing diameter of the tree. Four volume equations and tables were performed specifically over bark volume of top diameter 20 and 10 cm and similar ones for under bark. The lower values of RMSE, RSR, PBIAS, MAD, SDR and residual plots near by the zero showed high reliability of the equation. The volume table will be useful for calculation and evaluation of volume of the tree of *Shorea robusta*. Similar types of volume tables should be developed for other important species in Nepal. The factors affecting the volume of *Shorea robusta* is out of scope.

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